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CONTRIBUTION TO THE STUDY OF SPINA BIFIDA, ENCEPHALOCLE, AND ANENCEPHALUS. By Professor CLELAND, F.R.S., *Glasgow*. (PLATES XI. and XII.)

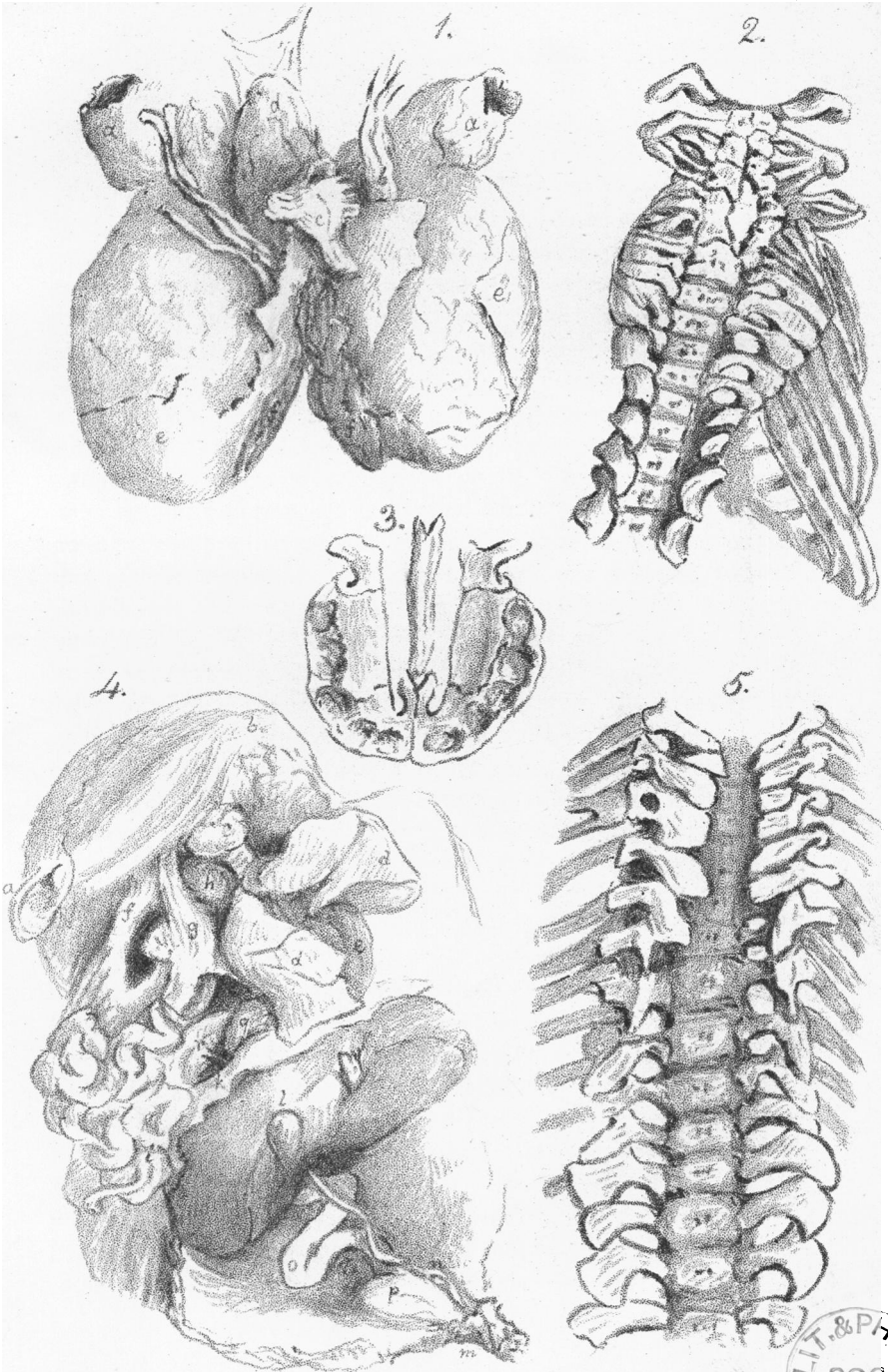
NOTWITHSTANDING all that has been written on such malformations as are included under the terms spina bifida, encephalocele, and anencephalus, and the recognition in a general way of their dependence on dropsy, or on deficient closure of the canal of the cerebro-spinal axis or its coverings, there yet remains room for a more detailed account of their anatomy, and a more explicit comprehension of their nature. This impression is not removed by reference to the recently published work, with Atlas, compiled from many writers by Ahlfeld,¹ nor even by perusal of the instructive pages of Förster.² I therefore make no apology for describing a few specimens with more or less full detail.

I. *Hydrocephalus and Spina Bifida in an infant born at full time.—Skeleton.*—The dried skull is about $5\frac{1}{4}$ inches long, $4\frac{3}{4}$ high, and $3\frac{1}{4}$ broad. The parietal bones exhibit deep notches and circular perforations at the upper and back parts; and on the upper border of the right parietal some ossa triquetra convert four deep notches into foramina. The frontal bones are much perforated at the lower parts of their frontal plates and anterior parts of their orbital; the orbital plates being completely separate, and other smaller ossifications intercalated between them and the frontal plates. The foramen magnum and cervical vertebræ are normal; but from the sixth dorsal downwards the spinal canal is open, the laminæ being spread

¹ Ahlfeld, *Missbildungen des Menschen*, Leipzig, 1882.

² Förster, *Missbildungen des Menschen*, Jena, 1861.

out to the sides in the lower dorsal and the lumbar regions; each lamina touching the lamina below it, and the last dorsal and upper lumbar laminae being greatly expanded (fig. 5). The 3rd and 4th ribs of the left side are fused in the whole extent of their heads and necks and for a quarter of an inch further forwards; and the corresponding vertebral laminae are likewise fused, leaving only a perforation between their united transverse processes. Also, the body of the 4th dorsal vertebra presents in front the appearance of two centres of ossification, the left one the larger. The left laminae of the upper six dorsal vertebrae are more expanded than in the normal foetus, and than the corresponding structures on the right side, and the first of them seems to be supplemented by an additional centre of ossification projecting behind and below it. On the right side the laminae of the 3rd and 4th dorsal vertebrae are normal; but an additional lamina without pedicle or transverse process is intercalated between the 2nd and 3rd. In the sacral region, only the 2nd and 3rd laminae turn inwards towards the middle line, and they are expanded. *Integument.*—In the first place may be mentioned a post-anal dimple bound down to the tip of the coccyx. In the middle third, between this and the head, is an oval space with a smooth thin covering, different from the surrounding integument, and presenting the well-known character of spina bifida, while at the upper end of this oval space or membranous area a minute aperture can be detected. *Cerebro-spinal axis.*—For purposes of exhibition, the spinal cord was divided $1\frac{1}{2}$ inches below the pons Varolii, and the lower part was removed in connection with the integument of the back, while the upper part was kept in connection with the encephalon. The corpus callosum and fornix had been destroyed by the distending effusion, while the hemispheres were in a state unfit for preservation. The optic thalami and corpora striata were normal, but the corpora quadrigemina were curiously altered in shape, the testes being projected above the nates, and the nates being flattened, probably by the pressure of the distended hemispheres. The cerebellum has its two lateral lobes completely separated by the vallecule; and in it the inferior vermiform process extends up so far, that what appears to be the pyramid touches the corpora quadrigemina, while the uvula looks back-

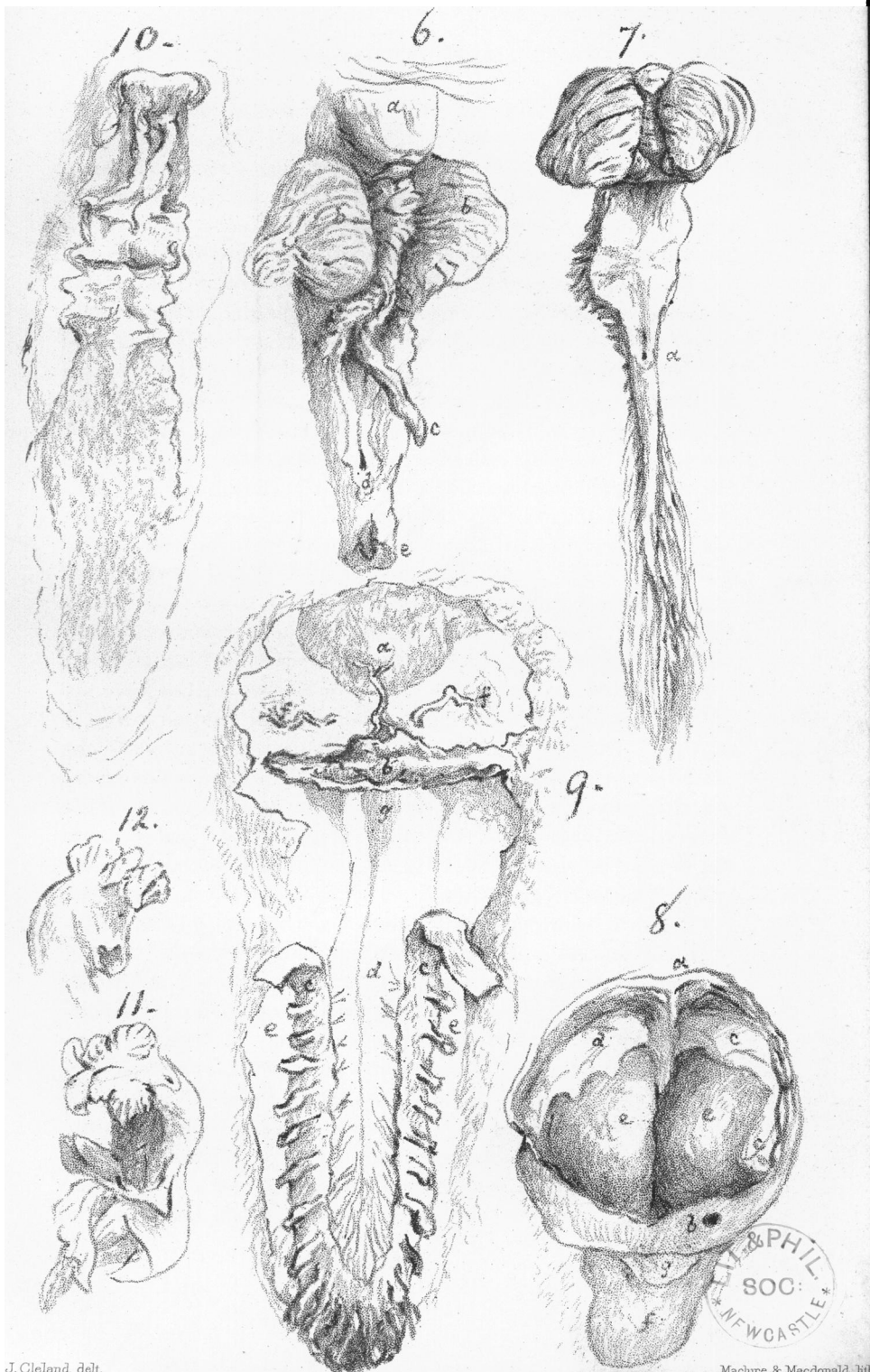


wards, and the laminated tubercle hangs down from an exaggerated velum posticum, as an appendix $\frac{3}{4}$ -inch in length lying in the prolonged 4th ventricle (fig. 6). The 4th ventricle extends to half an inch above where the spinal cord has been divided, and there presents an apparently imperforate depression at the end of the central canal of the spinal cord. But at the place where cut across, the central canal was dilated so much that it would admit a probe, and was traced up to within a quarter of an inch from the depression in the 4th ventricle. Turning now to the specimen prepared to show the remainder of the spinal cord and its connection with the integuments, we find that the perforation seen at the upper end of the superficial oval space is continued up into a dilated central canal, and that the cord terminates abruptly here. But division of the dura mater down the middle line in front of the cord has brought into view the continuation of the arachnoid space down to the lower end of the sacral canal, and the nerves on each side given off in order, and clothed with arachnoid. Each is provided with its ganglion outside the dura mater, and appears quite normal. Each root is traceable upwards and inwards, the anterior roots to near the middle line, and the posterior roots to a line on each side; and both are firmly connected with the superficial membrane. By dividing the posterior part of the dura mater on each side, behind the emergence of the nerves, what may be termed the posterior sac of the arachnoid is seen to bifurcate inferiorly opposite the termination of the cord. By slitting up the arachnoid in front, a large subarachnoid space has been brought into view, and a large anterior spinal artery, extending down at least as far as the middle of the superficial membrane of the spina bifida to the level where the 2nd sacral nerves take origin. A delicate layer of the superficial membrane has crumbled away in the manipulations to which the specimen has been subjected, and was no doubt the continuation of the grey matter of the cord, or the epithelium lining the central canal. The tougher layer on which this has rested is to be regarded as the representative of the pia mater and reticulum.

II. *Cervical Spina Bifida*.¹—The face and scalp are like those of

¹ Presented by Dr. Murdoch Cameron, to whose kindness I am also indebted for others of the specimens described.

an infant at full time ; but, judging from examination of the skull and from the limbs, I should think it is only an eight months' fœtus. It is female ; the back is short, the hairy scalp reaching to within 3 inches of the nates. A large fluctuating tumour was felt extending over the sides and back of the head, and down the back. The swelling came forwards to the ears, which are much misshapen, apparently in consequence of pressure. On cutting open the tumour, a larger mesial cyst was found, with an elongation of the 4th ventricle of the brain lying in the bottom of it. At the sides, some minor collections of fluid were separated by thin partitions from the main cavity. *Skeleton*.—The skull does not differ from a normal eight months' skull, except that the parietal and occipital regions are less developed, giving the shape normal at an earlier period. The palate is cleft, but the intermaxillaries fully developed. The twelve pairs of ribs are all present, the first pair having normal sternal attachments. The ribs are crowded together, elongated forwards, and bent inwards, so as to compress the thorax laterally. There are six lumbar vertebræ of normal appearance, and only six cervical vertebræ. The dorsal and cervical vertebræ are much altered ; those to which the five lower pairs of ribs are attached have the laminae directed outwards and expanded, with the centrum not deviating from the normal save in being broader ; while the vertebræ above these have not only their laminae directed transversely outwards, but a mesial gap completely separating the right and left moieties of their bodies ; and this gap extends into the upper part of the neck (fig. 2). The cervical vertebræ are greatly shortened and altered. The body of the axis is in two lateral parts, while no separate ossification seems to exist for the odontoid process. Below this, on each side, is a series of three half centra becoming fused together ; then follows on the left side a block of six such, and on the right side blocks of two and four in succession, all much crowded together. The right laminae of the 2nd, 3rd, 4th, and 5th cervical vertebræ are united externally into one lateral projection, and similarly the 3rd, 4th and 5th of the left side are united. *Cerebro-spinal axis*.—The cerebrum and cerebellum appeared normal ; but the distance from the under surface of the cerebellum to the extremity of the spinal cord is only $2\frac{1}{2}$ inches, of which $1\frac{1}{4}$ inch is open behind, so as



to form an elongation of the floor of the 4th ventricle. In the middle of this there is a transverse fold or pucker forwards corresponding in position with the mesial fissure seen in the cervical part of the column, and from this part nerves come off very crowdedly (fig. 7).

III. *Occipital Encephalocele*.—This specimen is of a kind well known in its general characters, having the greater part of the brain projecting behind the skull in the form of a chignon. It was named by the elder Geoffroy Saint-Hilaire “*Notencephale*,” and the skull was carefully figured by him.¹ Rising upwards and backwards from the head is an enormous tumour formed by the brain; it is of such size that it measures about 5 inches across and nearly 8 inches from its uppermost part to the chin. *Brain* (fig. 1).—Only the foremost part of each hemisphere, a portion of the size of a small walnut, was within the cranium, while the rest projected behind; the hemispheres being constricted slightly opposite the enlarged foramen magnum, which formed a circle $1\frac{1}{2}$ inch in diameter. In front of each hemisphere, occupying the very foremost part of the cranial cavity, was a little cyst about $\frac{2}{5}$ -inch diameter, with thin walls, which were torn into on removing the brain. These were probably dropsical olfactory bulbs. The interior of the hemispheres was in a condition unfit for dissection, but the surface was copiously convoluted. Their united mass exhibited a bilobate form due to the greater resistance offered by the falx cerebri than by the lateral parts of the dura mater to their expansion backwards. The positions of the origins of the 5th and 8th nerves were so far displaced backwards that these nerves ran a course of nearly three inches forwards before piercing the dura mater. The cervical nerves are all crowded together like the corresponding vertebræ, and the part of the cord from which they spring has maintained its position within the spinal canal, while the medulla oblongata has been so pulled backwards by the displacement of the cerebrum that it is quite unrecognisable; only, it appears from the relative positions of the 5th and 8th nerves that the upper part of the pons Varolii has been the portion of the base of the brain most thrown backwards, and that the part of the medulla

¹ *Mémoires de l'Académie des Sciences*, Mémoire lu en Octobre 1820; and repeated in the *Philosophie Anatomique*.

between the 8th cranial and the 1st cervical is the part stretched. In front of this stretched part lies an elongated basilar artery. The cerebellum is barely recognisable in two lateral parts sundered one from the other, much compressed, and carried backwards beneath the hemispheres. Projecting forwards in the middle line between the elongated nerves, and arising from the part of the base driven farthest back, is a hollow pouch about 2 inches long and $\frac{3}{4}$ -inch broad, with tolerably tenacious walls, like the finger of a glove. This is the infundibulum and lamina cinerea, and possibly includes the cerebral part of the pituitary body. At the tip of this pouch, in front, one can recognise stretched remains of the optic nerves and some slight vestige of optic commissure. *Skeleton*.—The highest vertebra with laminae united is the 2nd dorsal. The neck is short, and the bodies of the cervical vertebræ show evidence posteriorly of having been each ossified from twin centres. Their laminae remain wide apart from the middle line, and on the right side those of the 2nd and 3rd are completely fused behind their transverse processes, as also are those of the 4th, 5th, and 6th; while, on the left side, those of the 2nd, 3rd, and 4th are similarly fused, and those of the 5th and 6th. The base of the skull, as seen from within, has the petrous bones so bent downwards that their upper borders enclose between them superiorly an angle of 220° ; and it is so curved mesially that the clivus is at right angles to the united bases of the orbital wings of the sphenoid. The frontals are flat above, with their frontal plates pressed into contact with their orbital plates, and prolonged only a $\frac{1}{4}$ -inch farther back. On the right side the parietal is represented by two bones, an anterior of small dimensions articulating with the frontal and squamous, and a posterior much larger quadrate bone articulating with the mastoid and occipital, and with nearly the whole length of the left parietal. On the left side two corresponding elements can be distinguished, but are ankylosed. The supra-occipital bounds the enlarged foramen magnum in its dorsal moiety, and is only about $\frac{1}{4}$ -inch broad in the middle line, but is thick and strong. The palate is cleft in its whole length save in the intermaxillary part; and the vomer articulates with a pair of enlarged mesial palatine processes of the intermaxillaries similar to those found in many mammals (fig. 3).

IV. *Occipital Encephalocele, Open Spina Bifida, and Displacement of Viscera*.—This specimen is a female foetus of five months, with a large and solid cerebral chignon of the size of the rest of the head; and beneath this the spinal canal open in its whole length.

Skeleton.—The skull¹ differs from that of the encephalocele already described, in that the two lateral divisions of the occipital bone fail to meet in the middle line behind the parietals; but the vault is collapsed in the same fashion. Beneath the skull behind there is a deep recess, in which the membranes of the cord were carried forwards; and in dissecting them out they were found to cohere to viscera in front of the vertebral column through a mesial gap. This gap when displayed is of such size that the tip of a little finger might be forced through it, but when undisturbed has little vertical height; and it is bounded by a continuous ring of cartilage, which above is in continuity with the occipital bone, and at the sides consists of the centres of the cervical and upper six dorsal vertebræ divided and crushed together; while inferiorly the remainder of the column is continued straight down, the laminae of the six lower dorsal vertebræ and the five lumbar being expanded out laterally. The scapulæ are crowded up into close contact with the skull, but all the five trunks of the brachial plexus emerge normally from the altered column.

Cerebro-spinal axis.—The disposition of parts, so far as examined in the region of the spinal cord, agreed with that found in other cases of open spina bifida, *e.g.*, I. and VI. A broad membranous area extends down the back, but the integument is complete over the sacrum. This membranous area is continued up beneath the tumour representing the brain, and the smooth surface is continued over that tumour as in cases of more complete anencephalus; but the membrane covering the tumour is tough, firm, and fibrous, though dark and smooth and unlike true skin. It exhibits a small perforation on its upper part. On raising the collapsed roof of the skull, there were first seen two hollow sacs, placed symmetrically, with little cerebral substance in their walls; and between and beneath these was found a larger and more thinly walled pouch projecting forwards mesially from

¹ Similar to that figured by Isidore Geoffroy St. Hilaire, *Histoire des Anomalies*, pl. viii. fig. 5.

the brain behind. The lateral pouches, probably olfactory bulbs, showed considerable dimensions when floated out in spirit, and the mesial pouch likewise was then seen to have a considerable cavity. Its membranous wall was so thin that it was much damaged in the removal, but the pituitary body adherent to it shows it to be the infundibulum. A delicate membrane also floats loosely in the angle beneath the tumour, in the position for the 4th ventricle. Thus there would appear to have been considerable effusion. Elongated fifth and other cranial nerves could be made out as in specimen III. Within the fibrous covering of the tumour, a very definite brain-structure is found. Two hemispheres project backwards and form its upper half, but, so far as exhibited, are solid; they are slender and become sharp-edged posteriorly (fig. 8). They overlie two lateral masses with smooth upper surfaces, which manifestly consist in greater part of optic thalami, though it might be difficult to decide how far corpora quadrigemina and other parts enter into their composition. Between these bodies a groove is continued down into the mesial hollow sac already described as lying on the base of the skull, so that the sac in question is manifestly an expanded infundibulum, like that of specimen III. Lifted up with the part of the brain raised by the section made, is seen a structure descending between the hemispheres, manifestly consisting of falx cerebri and other mesial structures. *Viscera.*—The adhesion of the dura mater in the neck to some viscus suggested the propriety of opening the visceral cavity (fig. 4). Beneath the liver in the abdomen are seen the two kidneys, and in the middle a slightly convoluted intestine continued up from the rectum, but neither stomach, spleen, small intestine, nor cæcum. From the umbilicus to the site beneath the liver where the intestines become invisible, extends, passing on the left side of the intestine, a long slender cord, one of the cords described by Allen¹ and recognised by him as vestiges of the omphalo-mesenteric vessels, remaining till after birth in various animals, but not found by him in the human subject at a period later than when the trunk from vertex to coccyx was 3 inches long. On laying open the thorax and neck, a tumour was found in the posterior mediastinum. It was cut into from the right pleura, and found

¹ *Jour. of Anat. and Phys.*, xvii. p. 59.

to contain a prolongation from the peritoneum ; and, covered by this, was laid bare the stomach which extended from the level of the lower bodies of the larynx down to the diaphragm, with the lesser curvature turned to the right and backwards. To the upper part of the lesser curvature is attached some tissue, which is that which has been adherent through the gap in the vertebral column to the dura mater, and appears to be connected with the pancreas. From the greater curve of the stomach, turned to the left, a peritoneal covering extended over a mass of intestines ; and having divided this, I find that it is the great omentum carried over the intestines so as to enclose them in a manner similar to that described by me as occurring in an anomalous instance many years ago.² The neck of the enclosing hood formed by the great omentum is, as in that instance, quite a narrow opening. It is situated at the pyloric end of the stomach, immediately above the opening between the crura of the diaphragm, by means of which the intestines have been drawn up into the thorax. The portal fissure is, as it were, pulled back to the posterior wall of the abdomen by the connection of the bile duct with the intestine just beyond the pylorus ; and consequently the lobulus Spigelii is drawn upwards so as to be visible from the thorax. The spleen is in its proper relation to the stomach, namely, at its cardiac end, which is situated in the neck. The cœliac axis and superior mesenteric artery are both given off in the thorax ; the inferior mesenteric and the renal arteries arise in the normal manner. The omphalo-mesenteric cord passes up into the thorax, and ends in the mesenteric vein.

V. *Encephalocele, Spina Bifida, and Anencephalic Skull.*—This is a female fœtus of six months. I need only mention the points which give it interest in connection with the other specimens. The back is much shortened, the whole of the dorsal as well as cervical vertebræ being involved in the part drawn up into a deep concavity below the skull. The membranous area over the open spina bifida extending to the base of the sacrum, has a quantity of vascular tissue in it, friable and difficult to dissect. Overhanging it is a large cerebral tumour, about the size of the rest of the head, and covered with tough smooth

¹ *Jour. of Anat. and Phys.*, May 1868.

covering like that described in specimen IV. On lifting this tumour by dividing the integuments in front of it, elongated fifth and other nerves were brought into view, and a mesial hollow structure, but no roof bones, the base of the skull being that of a typical anencephalus. On cutting open the tumour, it was found impossible distinctly to recognise any of the normal parts of the brain; but there was abundance of cerebral substance thrown into irregularities round a hollow prolonged forwards to the base of the skull, and attached in the sphenoidal region.

VI. *Anencephalus with Open Spina Bifida, and Small Cerebral Tumour*.—This is a female foetus of more than six months. It measures 7 inches from the upper end of the anencephalic membranous area of the head, down the back to the anus; and of this 5 inches are open cerebro-spinal axis, leaving 2 inches of sound skin between that and the anus. Half an inch above the anus is a post-anal dimple connected with the tip of the coccyx. On the fore half of the cephalic area is a hollow tumour the size of a cherry, with an opening a fifth of an inch in diameter at its back part. It is hollow, lined with a fine smooth surface thrown over a number of ridges and corrugations and processes of a soft substance evidently cerebral. The membranous covering of this tumour is thicker and whiter than that belonging to the spinal area. Behind the head the membranous area is bound firmly down by dense tissue, which has fitted into a depression behind the head, in which are involved some of the bodies of the upper dorsal vertebræ, while the cervical bodies are unrecognisable. The 1st and 2nd ribs are close up to the skull, and the angle of the scapula is crowded in between the skull and them. After dissecting off the integuments of the back along with the membranous cerebro-spinal area, the spinal ganglia of the dorsal and following nerves could be seen in two rows on the deep side of the parts removed; and, cutting down in the middle line between the spinal nerves, a continuous arachnoid sac was laid open in front of the anterior roots, which were seen arising near the middle line from the superficial membrane (fig. 9). Those, however, above the middle of the dorsal region could not be made out. The posterior roots of the spinal nerves come off in rows about a fifth of an inch from the middle line. But above the middle of the dorsal region these also are

absent, though the spinal ganglia can be made out. The arachnoid sac between the anterior roots is wide above; and, inserting the scissors external to the row of ganglia, I have on each side followed down a sac which corresponds with one-half of the part of the arachnoid space which normally lies behind the ligamenta denticulata. It is separated from the anterior sac, partly, as is usual, by the ligamentum denticulatum, and partly by an uninterrupted fold continued down over the roots of nerves. Superiorly, the arachnoid sac is traced up on each side of the dense tissue filling the hollow beneath the back of the head, and each half unites with its fellow on the base of the skull. Here also can be made out a basilar artery formed from two vertebrals and dividing into two posterior cerebrals, and, on each side, an origin of the fifth nerve; but other details I am unable to identify. Descending from the dense tissue at the infracephalic depression, is a pyramidal thickening of about an inch in length, whence proceeds downwards a mesial cord, which may be the anterior spinal artery, but it is not injected. On each side of this a finer line descends, which is probably the white band normally found in the ligamentum denticulatum.

VII. *Another Anencephalus with Open Spina Bifida*.—This specimen is a male about the same age as the last. Like it, it shows arachnoid sacs disposed between and beyond the roots of the spinal nerves. In this instance small lateral vascular masses are the only elevations on the base of the skull; but the arachnoid is traced forwards to the front of the cephalic part of the membranous area. The cervical vertebræ can be made out, although all fused together; and the cervical and upper dorsal nerves arise superficially as much as an inch below their emergence, that is to say, their origins from the membranous representative of the cord are situated towards the middle of the dorsal region, and in their course to their places of emergence they form a sort of cauda equina directed upwards.

VIII. *Anencephalus with Foramen Magnum completed*.—This is a fully developed female infant, with the neck and back normal, and a spongy mass occupying the membranous area over the head. On proceeding to remove this mass along with the skin round about from the skull, it was found that the occipital bone completed an arch over the foramen magnum, although

the two lateral parts which did so were yet unanchylosed in the middle line above. A mesial incision was made, and these two lateral parts prised asunder in order to remove the protected cranial contents along with the exposed spongy mass. The skull presents characters approaching those figured under the name of "podencephalus" by Geoffroy St. Hilaire in plate vi. of the 2nd volume of his *Philosophie Anatomique*, but differs from it, and much more from the podencephalus figured in plate ii., in having the occipital less complete and the base more exposed.

The spongy mass removed with the integument was found to be surrounded with a capsule of dura mater, and this being opened exhibited a falx well developed in front and coming to a point behind, while on each side, placed symmetrically, was brought into view an elongated vesicle stretching by the side of the falx, and another extending outwards from its fore part. These vesicles were embedded in dense connective tissue laminated and vascular, an obvious development of pia mater, and on being opened were found to be entirely devoid of nervous substance. From beneath the protection of the occipital arch a perfect medulla oblongata has been removed, but it ends abruptly above, not far from the posterior extremities of the longitudinal vesicles; and there is no vestige of cerebellum, the sides of the posterior fossa basis cranii having been occupied by two masses of tough leathery substance instead. The cervical vertebræ and the muscles at the back of the neck are normal.

IX. *Anencephalus without Supra-Occipital, and without apparent Spina Bifida*.—Fully developed female infant. In this instance there seemed to be scarcely any spongy mass beneath the membranous area. The little that was detected was in front, but the petrous bones seemed covered with mere membrane. Behind this, near the back part of the membranous area, which was confined to the head, a pit was detected which proved to be a foramen passing down into the interior of the cord. The spine of the axis was normal, with muscles normally attached; but the posterior arch of the atlas was incomplete, a state of matters not very uncommon in otherwise normal subjects. A few of the cervical spines having been split up, the upper part of the cord was removed along with the membranous area which was stripped from the skull. The slight intumescence of this area

in front was then found to depend on a quantity of tough blood-stained tissue which adhered to the fore part of the exposed base of the skull. The clivus was found, when traced downwards, to be bent forwards under the skull, completing, with the bodies of the vertebræ beneath, a recess in which the medulla oblongata was lodged, and lying at an angle less than a right angle with the upper surface of the body of the sphenoid, which also, as is habitual in anencephalus, projected upwards between the petrous bones, by reason of the outer ends of these latter being depressed. On splitting the dura mater in front of the cord upwards, the arachnoid space in front of the nerve-roots was laid open and the medulla oblongata exposed, crossed above by a delicate transverse band representing the pons Varolii, while on each side was a delicate structure readily recognised as the flocculus, but not a vestige of cerebellum.¹ The arachnoid sac was pursued further forwards, spreading out to each side in a position corresponding with the prominent edge of the petrous bone. Towards the fore part of the membranous area a small opening in the middle line was found overhung by spongy substance, and leading into a sac about an inch and a half in breadth and half an inch in length, with two smooth symmetrical masses, united by a narrow isthmus, projecting from the roof, obviously representatives of portions of the brain, doubtless the hemisphere vesicles. Thus in this specimen there were two openings from the membranous area, one leading back into the interior of the medulla oblongata, and the other forwards to the termination of the cerebro-spinal tube in front.

In addition to these nine specimens, selected from among a number of human malformations presented to my predecessor and myself, I shall describe two specimens of chicks, the importance of which might have escaped my notice had it not been for the instructive memoir published in 1881 by Dr. Lebedeff,² in which he describes various specimens of anomalous brain and

¹ The flocculus, though always described with the cerebellum, is very well understood, by those who have studied its development, to be totally unconnected with that organ, being developed from a lateral outgrowth of the floor of the 3rd cerebral vesicle, while the cerebellum is developed further forwards from the foremost part of the roof of that vesicle.

² "Ueber die Entstehung der Anencephalie und Spina bifida bei Vögeln und Menschen," Virchow's *Archiv*, lxxxvi. p. 263.

spinal cord in the embryo chick, and points out their bearing on anencephalus in the human subject.

X. *Embryo Chick* (fig 10).—This specimen exhibits the open condition of the cerebro-spinal canal found in the first day of hatching. But the open condition is in this instance anomalous, for there is an overgrowth of the cerebro-spinal axis; the parts apparently corresponding with the greater part of the cerebral vesicles being much thickened, and the part immediately behind, namely, that which appears to represent the anterior cervical region, being thrown into numerous plications as well as expanded, while the expanded condition is carried back the whole length of the embryo.

XI. *Embryo Chick; Cyclopia* (figs. 11 and 12).—This is a chick hatched for nine or ten days. The principal peculiarities are confined to the head, which is turned to the right side and surmounted by exposed brain forming a lobulated mass overflowing the base of the skull, and consisting of an open ventricle with a largely developed laminated mass on each side, apparently the right and left moieties of the cerebellum, and smaller masses in front of these. On the surface there was no appearance of eye nor of ear, and instead of a beak there was an elongated projection with an irregular aperture at the extremity, which suggested the idea that it was such an orifice as is seen in agnathia of mammals, combining mouth and ears in one. This view was corroborated by opening the orifice up, when one side of the lower jaw was found ending in a point at the side of the aperture. Also, in the floor of the cavity, when cut up, was seen a pimple representing the tongue. But what was most remarkable was a minute cyclopic eye, detected by being black with choroidal pigment, but minute, and situated so deeply that it could not be seen till the dissection was made.

GENERAL REMARKS.

By placing together more or less detailed accounts of the anatomy of nine different instances of imperfection of brain and spinal cord in the human subject, there is exhibited the close connection between conditions conveniently described by different names, and even yet too often looked on as thoroughly distinct.

The first impression, on looking at numbers of monstrosities, is that the different groups are each one remarkably distinct from others, while its members are remarkably similar. It is afterwards that the links between them strike us; and one quite understands the reasons which led the great Geoffroy St. Hilaire to believe them capable of being distinguished in a way perfectly similar to that in which zoological genera and species are determined. It is not to be forgotten that his work in respect of monsters was governed by a desire to develop a philosophy of anatomy. He saw in monsters, as in zoological genera and species, the operation of external surroundings on the internal formative impulse of the organism, or, so to say, of environment on heredity; and if he had not the opportunity of appreciating the connecting links between diverse forms of monstrosity, he was the first to suggest the possibility of change being effected by environment in zoological species, to which he considered that monsters stood in an appreciable relation. It may further be noted here that the considerations about to be laid before the reader in the remainder of this memoir point out that the principle put forward by St. Hilaire, namely, the direct action of environment on form, is the source of modification of the embryo by sudden change in individual instances to such an extraordinary extent as to suggest that its influence by gradual and continued change operating on the embryo in successive generations cannot be easily estimated. The principles enunciated by Lamarck, St. Hilaire, and Darwin respectively, namely, the hereditary transmission of the effects of habitual actions, of environment, and of natural selection, all have their places in nature. As to whether any of them or all combined are sufficient to produce higher forms from lower that is a different question, and one not likely to be settled by dogmatic asseveration or even the insulting jibes which occasionally disgrace the London press.

Where St. Hilaire went wrong with regard to monsters seems to have been principally in making an arbitrary distinction between pathological action and arrest of development, and denying the pathological element; apparently not sufficiently appreciating that pathological and physiological action are both excited by stimulation from without, and only differ in respect that in pathological action the normal sequence of events in the

organism is altered. An arrest of development presupposes some cause of the arrest, and, according as the cause varies in character, time, site, and degree, so do its effects vary, without being so specifically distinct as they at first appear.

In the first of the specimens now described an open spina bifida, or complete "rachischisis" of the lumbar region, is seen in association not merely with hydrocephalus, but also with a dilated condition of the central canal in the intervening cord. In the second specimen a cervical spina bifida covered with natural integuments presents want of closure of the central canal and of the vertebral arches, and also shortening and bending forwards of both cord and column, accompanied with a certain lateral expansion. In the third specimen, while the brain is displaced and the skull deformed in consequence, the changes in the cervical part of the column are of a similar character to those in the previous specimen, while there are again unmistakable signs of accumulation of fluid, though in this instance intracranial. In the fourth specimen open spina bifida in the whole length of the cord accompanies a displacement of the brain very similar to that in the third specimen, though uncovered with true skin, and with the occipital bone less developed. In the fifth specimen an open spina bifida is surmounted by a cerebral tumour similar in appearance to that of the previous specimen; but when the tumour was opened into, the brain was found to be less developed; and the skull was that of a typical anencephalus. In the sixth specimen we have an anencephalus with a small cerebral tumour perforated near the back, so as to be continuous with the open spina bifida; and in the seventh specimen complete anencephalus with open spina bifida is illustrated in simplicity.

The eighth and ninth specimens are instances in which the lesion is confined to the skull and its contents; and it is noticeable that while in both there is a medulla oblongata, the brain is a shade less interfered with in specimen nine, in which the skull is completely unroofed and enormously bent out of shape, than in specimen eight, which has occipital elements roofing over the medulla oblongata. This is an additional illustration that interference with the brain and interference with the skull do not march *pari passu*.

ORIGIN OF ANENCEPHALUS AND SPINA BIFIDA.

The connection of these anomalies with dropsies in the embryo has been maintained since Morgagni wrote till now. Geoffroy St. Hilaire refers to Meckel and to Tiedemann as recognising in such affections an arrest of cerebral development, and has elaborated a like view, holding that there is an accumulation of fluid, but that this is not the result of disease but the persistence of the embryonic condition when fluid is normally contained within walls in which the nervous substance is not yet developed. It is plain, however, that St. Hilaire believed in the existence of a membranous pouch containing between two and three litres, or about half a gallon of water, attached round the margins of the membranous area of the specimen of anencephalus and open spina bifida which he was describing, although he saw no vestige of such a thing himself, but managed to get an account of it, vague enough, from the midwife, after having arrived at the conclusion that such a thing must be.¹ That such a pouch actually did exist in that particular instance I am not prepared to deny, seeing that it is perfectly conceivable, and would furnish an intermediate condition between spina bifida completely open and that which is covered with true integument, but undoubtedly in none of the many instances of spina bifida and anencephalus that I have seen have I detected traces of such a thing, and in none that are now within my observation is there the slightest interruption of continuity between the integument and what I term the membranous area. Isodore Geoffroy St. Hilaire adheres to the views of his father, and speaks of the integuments being replaced before birth by a "vast hydrorachic tumour," of which nothing is left but irregular débris.²

The views of Dareste appear to coincide entirely with those of St. Hilaire. He speaks of the brain and spinal cord being replaced by a pouch full of serosity, at some distance from which the integuments cease.³ He calls it a physiological dropsy, and says "this accumulation of serosity hinders the

¹ *Philosophie Anatomique*, ii. 131.

² *Histoire des Anomalies*, ii. 360.

³ *Production Artificielle des Monstruosites*, 1877, p. 248.

formation of the nervous substance." He further suggests, as the initial deviation from normal growth in anencephalus, pseudencephalus, and exencephalus, an arrest in the development of the "cephalic hood which causes it to remain applied to the superior aspect of the head, and to compress it in part or altogether,¹ and in this idea he is followed by Perls² and Marchand.³

Förster describes anencephalus and spina bifida, or, as he terms them, cranioschisis and rachischisis, under the head of *Hydrops canalis medullaris*, and describes them thus:—"The original collection of water is so considerable that a fissure is thereby effected of the osseous walls and coverings of the medullary canal, and a more or less perfect destruction of the brain and spinal cord." He states also that the dura mater and other membranes of the brain in anencephalus form a great sac which covers the whole base of the skull, or bursts so as to leave the base covered with the exposed remnants of the membranes and of the brain.⁴

Ahlfeld,⁵ while admitting that other causes combine to produce anencephalus, considers that none can compare in frequency with cerebral dropsy; and he dismisses as unsupported the views brought forward by Lebedeff. Lebedeff's memoir, however, is one of the utmost importance. For it will be seen that in all previous views an accumulation of water has played an important part, whether looked on as a purely pathological accumulation or not; but Lebedeff points out among other things, and figures abnormal conditions of the young embryo chick, in which closure of the cerebro-spinal cylinder has failed to take place. The blastema for the roof of the skull and spines of the vertebræ fails in these cases ever to reach the middle line; and there can be no thought of their having been turned aside by the pressure of a bag of fluid. Lebedeff figures three such cases, and gives vertical sections of others, showing that there is an undue thickness of the medullary plate, and that complicated foldings of it occur, with consequent formation of adventitious vesicles. He concludes that anencephalus occurs in consequence of changes of

¹ *Op. cit.*, p. 254.

² *Lehrbuch des Allgemeinen Pathologischen Anatomie*, p. 283.

³ Referred to by Ahlfeld, *op. cit.*, p. 290.

⁴ *Op. cit.*, pp. 77 and 80.

⁵ *Op. cit.*, p. 290.

the medullary plate in the earliest stages of embryonic life, either while as yet the medullary furrow is open or at a later time; the tube either having never been closed or having flattened out, and its hinder wall given way.¹

Importance is due to the observations of Lebedeff, which are supplemented by Specimen X. of this communication, first, because they demonstrate that failure in closure of the cerebro-spinal axis is a thing which does occur, and therefore which may be found in an older embryo as well as a younger; and, secondly, because the development of nerves in regular series, and of both anterior and posterior divisions of the arachnoid sac, is not likely to have gone on with uninterrupted regularity under the pressure of a collection of fluid so destructive in its effects as to have destroyed by pressure the brain or spinal cord. The regular origin of the nerves was brought forward by Geoffroy St. Hilaire as evidence against a pathological collection of fluid; but, so far as I know, the circumstance of the portion of the arachnoid sac normally posterior to the roots of nerves being developed in two divisions external to them has not ere now attracted notice. Its significance consists in this, that while the substance of the spinal cord is represented by no more than an epithelium, the part of the arachnoid which should have been behind the cord pursues its development in its displaced position exactly as is the case with the laminæ of the vertebræ.

While, however, anencephalus and spina bifida exhibit deficient development of brain and spinal cord, the chicks described by Lebedeff present over-development of the medullary blastema; and in Specimen X. above described, such over-development is shown in two ways, namely, by thickening and by plication. But the medullary blastema would not be plicated were it at liberty to extend at an increased rate longitudinally. An equally increased growth of all the parts would simply yield a larger embryo of normal form. The plications arise from connection with a mesoblast growing at a slower rate. So also, in one of the embryos figured by Lebedeff, though there is no plication, the undue elongation of the fore part of the medullary plate appears to have produced increased cephalic curvature or kyphosis, and the same thing has happened in the embryo

¹ *Op. cit.*, p. 297.

chick, Specimen XI., above described. Lebedeff, indeed, points out that flattening of the brain part of the medullary plate would be a mechanical consequence of increased curve, just as one flattens a half tube of india-rubber by bending it backwards; and this may be considered as an element having its value; but it is not necessary to resort to any other explanation than the overgrowth to account for patency of the tube. In another somewhat older embryo figured by Lebedeff, one in which the limbs have appeared, the whole embryo is thrown into a letter S curve in a manner common enough in artificial incubation, apparently because the surrounding membranes have cramped it longitudinally. But the undue expansion of the medullary plate is not only longitudinal; it is likewise transverse; and if this transverse expansion be especially in the superficial layers, it will manifestly exercise an everting influence on the sides, and prevent their turning back in the normal way to meet in the middle line. The normal inversion of the edges of the plate is produced by a comparatively greater growth of the deep than of the superficial strata, and an equal growth of both would be sufficient to keep the furrow wide open.

Recalling to mind what a fruitful source of abnormalities unequal temperature is in artificial incubation, a subject to which both Dareste and Panum have given special attention, we need have little hesitation in referring numbers of abnormalities to the effects of accidental stimulus acting on the whole embryo or on a part; and if it further be kept in mind, that while gentle and recurrent stimuli may increase the vital energies, a sudden and prolonged exaltation of action is followed by exhaustion, we need not, I think, deem that there is necessarily any improbability that abnormalities presenting deficient development of parts have originated in the excessive growth of those parts at a very early period.

The abnormalities under consideration in the chick have all the appearance of depending on undue stimulation, at a very early date, of the whole or part of the cerebro-spinal axis; and the effects so produced we now see may be rationally considered sufficient to prevent the closure of the neural cylinder. We may go further, and *even if we shall find reason to believe that spina bifida and anencephalus result from the rupture of an*

already closed cylinder, refer the abnormal condition to overstimulation in the first instance. The pouring out of fluid by living corpuscles is an effect produced by stimulation carried on in some particular manner and to a certain degree, though of the *modus operandi* in detail we know little or nothing. This is illustrated by the action of vesicants. The collection of fluid in an already closed cerebro-spinal cylinder is doubtless also an effect of over-stimulation of the living corpuscles in a certain manner and degree. The proliferation of these corpuscles in a manner such as to produce tissue of healthy consistence, but of undue amount, is likewise the result of external irritation or stimulation acting on the internal impulse or vital properties; but the adjustment of the two factors is in different proportion. Thus there need be no radical distinction, so far as the first cause is concerned, between an abnormality produced by non-closure of the medullary tube, and one due to a collection of fluid at a slightly later period. In both instances there is undue action in the originally superficial tissues of brain and spinal cord. In the one case the increased growth everts parts which ought to turn inwards, in the other the collected fluid pushes back the edges which had already become united.

Recognising, therefore, that abnormality may originate in both of these ways, seeing that on the one hand non-closure of the cerebro-spinal tube actually occurs in embryo chicks, while on the other spina bifida with complete closure of the integuments in the middle line is common, the question to solve is, whether in anencephalus and open spina bifida the abnormal conditions have originated before or after the period for closure; and this can only be determined by attention to the evidence afforded by the details of their structure.

From this point of view Specimen I. is highly instructive. Here you meet with actual hydrocephalus combined with an open lumbar spina bifida, the margins of which exhibit no trace of a rupture, but an uninterrupted passage from the normal epidermis to the delicate covering of the membranous area, and the arachnoid arrangements opposite the spina bifida are completely developed without trace of any result of inflammation. This is exactly such a spina bifida as might be supposed to originate from non-closure. But we have seen that, continuous

with its upper part, there is a dilated central canal where the spines and spinal cord are complete, and even the peripheral appearance of the cord remained normal, notwithstanding the dilated canal. This dilatation of the canal may indeed have arisen from want of normal development of the nerve substance surrounding it, but as one might expect that such a want of development would have arrested the growth of the cord in diameter as well as in the thickness of its proper substance, it is perhaps more likely that distension of the canal, after closure, caused its dilatation above, and led to its rupture below in very early development, while as yet there was little texture deposited in the middle line. The hydrocephalus was obviously of much later origin, when the different parts of the brain were already formed.

But more important than the teachings of this single specimen is what is to be learned from the consideration that in anencephali generally the eyes and their surroundings are normally developed. The primary optic vesicles are not separated from the vesicles of the brain till considerably after these latter have been roofed in ; and the evidence already given that structures are modified in their development by alterations in their mechanical relations, together with further evidence to the same effect about to be given, makes it very improbable that hollow organs ordinarily developed in connection with a closed cavity would exhibit the normal form in instances in which that cavity remained open.

The eyes of anencephali have been made the subject of special investigation by De Wahl and Manz,¹ and their only deviation from normal development consists in the absence of nerve fibres from the optic nerve and retina. That, no doubt, is a circumstance in itself very interesting ; it contrasts with the full development of the spinal nerves, and may suggest a question as to whether embryologists are right in translating the beautiful observations of F. M. Balfour on the early connection of the spinal nerves with the cord, as sufficient proof that these nerves are epiblastic in origin. But, taken in connection with the otherwise normal development of the eye, it cannot be looked on as showing more than that the rupture of the cranium in

¹ Manz, Virchow's *Archiv*, li. p. 315, where also reference is made to E. de Wahl.

anencephalus has occurred before the development of nerve fibres in the optic nerves and tracts. I apprehend, therefore, that *anencephalus most probably results from rupture of closed parts after the optic nerves have ceased to be tubes of communication between brain and eye*, and that such a form as the chick, X., the result of stimulation at a considerably earlier date, would be doomed to perish in the early stages of development. Panum¹ figures a chick hatched for 112½ hours, but of a development which suggests not more than sixty hours, with a beautifully broadly open lumbar spina bifida. I am not prepared to say that such a case as that has not been produced by non-closure, but lumbar spina bifida differs in some very important points from anencephalus and cervical spina bifida.

Lumbar spina bifida is not usually associated (I suppose, indeed, never is) with shortening of the vertebral column at the part, while there would appear to be always shortening of the column with cervical spina bifida; and anencephalus when complete is associated with cervical spina bifida. On the hypothesis, then, of undue growth, in the early embryo, of the medullary plate as compared with the subjacent structure, we shall see in lumbar open spina bifida the result of thickening or transverse growth, but without evidence of abnormal elongation; while in reference to cervical spina bifida the question arises, how far the elongation may be merely comparative, and arrest in elongation of the notochord be the real abnormality. As far as I can see, *the phenomena of cervical spina bifida can be accounted for by mere want of extension of the notochord*, while the medullary plate grows on at the normal rate; but since it is certain that very early overgrowth of the medullary plate does occur while as yet the parts for the dorsal and lumbar regions are but little developed, it appears very probable that the same stimulus which has that effect is also the cause of the non-elongation of the notochord. For this failure of the notochord to elongate is not to be accounted for by mere absence of its structure, which would offer no resistance to the elongation of the parts around but must be the result of an abnormal deposition firm enough to bind the surrounding parts to some extent.

¹ "Untersuchungen über die Entstehungen der Missbildungen, Zunächst in den Eiern der Vogel," 1860, Taf. vi. fig. 8.

Suppose the notochord to refuse to lengthen while the centres of growth for the bodies of the vertebræ have still the normal tendency to increase in size, the elongation of these will bend them outwards, making it more difficult for them to unite in the mesial plane, and thus broadening the bodies of the vertebræ, or pushing their right and left parts asunder, as we have seen occurs.

But what, then, is the cause of the convexity forwards of the shortened part of the column which is uniformly found accompanying cervical spina bifida? It is explained at once by the visceral arches being normally developed, though crowded on a shortened base. The effect of a comparatively large growth on the ventral aspect of the arrested notochord will be to bend the embryo back, on the same principle that growth on the dorsal aspect at an earlier date bent it forwards. But when the shortening of the column is very considerable, the bending backwards is insufficient to give room for the normal amount of growth of the dorsal and ventral plates, and I suppose they are thus constrained to continue further in a ventral course, leading to the length of ribs and great antero-posterior diameter of the thorax which are found in such cases. Another mechanical factor may, however, co-operate to that result. The rotation outwards of the walls of the neural canal involves the rotation forwards and inwards of the outer border of the dorsal plates, and a consequent diminution of the transverse diameter of the thorax, the ribs passing more directly forwards. One would anticipate that the same inward rotation of the visceral and maxillary lobes of the neck and face would favour the union of these parts in the middle line at a somewhat earlier date than usual, and lead to a certain upward pressure of the parts within their circle. On the other hand, the vault of the skull having been ruptured, there is an absence of that pressure downwards which is exercised in normal circumstances by the growing brain pressing on all its surroundings. It is owing to these causes that in anencephalus the base of the skull is bent downwards at the sides, as has been correctly noted by various authors. Perls alludes to this circumstance as an argument against dropsy as the cause of anencephalus; and it is a valid argument against a later dropsy being the cause, but not against an expansion leading to very early rupture of the vault.

On the hypothesis that all the abnormalities which we have been considering are consequences of over-stimulation in early embryonic life, it is obvious from what has been said that much difference of result will depend on the exact period at which the stimulus is applied. Speculating in a more tentative manner, I incline to believe that such over-stimulation, occurring soon after impregnation of the ovum leads to fissiparous division of the germinal mass, resulting in two embryos; that at a later period, or carried to a slighter extent, it will cause partial division, resulting in such forms of double monster as have a portion of the cerebro-spinal axis undivided; that at a later period, when the cephalic end of the neural furrow is formed but is still open, it produces such conditions as we have seen in the chick X., but that, in consequence of interference with their whole form, embryos so affected probably always perish early; that anencephalus is produced by rupture after the primary optic vesicles are cut off from the cerebral vesicles; and that lumbar spina bifida occurs later.

In an attempt to account for so many things by similar causes, one naturally asks, What is the relation of cyclopia and pericephalus to anencephalus? On that subject we may get some light when we study the conditions of the brain, as we must now do, to complete our view of the causation of the latter.

THE BRAIN AND CORD IN ANENCEPHALUS, ENCEPHALOCELE, AND SPINA BIFIDA.

I have already drawn attention to the very general presence of the arachnoid sac, and have thereby removed all possible ground for doubt that the membrane stretched instead of skin over the base of the skull in anencephalus, and over the vertebrae in open spina bifida, is in the main the surface of the medullary groove which has either remained open from the very first, or, as I think is more frequently the case, has become reopened by redundant collection of fluid and growth of substance very soon after closure. Thus, it is easy to recognise that a membranous area on the back is an enlarged central canal of the spinal cord, and that the texture between the surface and the arachnoid sac, however thin, contains whatever represents the substance of

the cord and the pia mater; and, indeed, a certain development of pia mater may render it spongy and vascular. The masses of spongy vascular tissue surmounting the base of the skull in most cases of anencephalus are nothing else than redundant pia mater. But we cannot consider the membranous surface on the skull of an anencephalus as corresponding in all cases, or even in most, altogether to the interior of the ventricles of the brain, seeing that in many instances a hollow vestigeal brain is present, and the hollow in these instances is the true ventricular cavity of the brain. Nevertheless, such a vestigeal brain, however much it may approach full development, is never covered with true skin, but only with dura mater, and a transparent membrane adherent thereto. That transparent membrane, therefore, must be looked on as a sort of adventitious outgrowth of the lining of the central canal and ventricles of the brain, beneath which the dura mater is continued round towards the middle line. Specimen VI. illustrates very well such a state of matters.

The very existence, however, of a hollow brain indicates a state of matters not touched on in the preceding remarks on the causation of anencephalus. It indicates that while the roof of the skull has been ruptured, there has been an unruptured part of the roof of the brain. In Specimen VI. the foramen at the back of the hollow tumour indicates where the wall of the brain has given way. This must have happened before the rupture of the surrounding parietes from which the integuments and bones take rise, for the regular development of the arachnoid space renders it unlikely that there had been effusion in the embryo between the cerebro-spinal axis and the parietes, and the gratuitous supposition that such a thing had occurred would in no way remove the necessity for supposing that effusion within the hollow of the axis had existed as well. It would appear, therefore, that a small rupture of the brain wall has relieved the pressure in the ventricles, while the superficial parts, continuing to be pressed on, and being much thinner along the middle line than elsewhere, are soon afterwards ripped up the middle more extensively. Probably this is the sequence of events in every instance in which the brain is represented by a vesicle with corrugated inner wall, as in Specimens V. and VI. and also IX., for the corrugations seem to indicate relief from internal pressure.

But every brain uncovered with true skin has not necessarily undergone rupture; it may by distension and displacement have ruptured the integument, while remaining itself unruptured. It seems probable that this is what has occurred in Specimen IV.; and, in fact, that case has much resemblance to the occipital encephalocele, Specimen III., save that it is complicated by open spina bifida, which very likely aided the rupture of the integuments of the head by giving a notch from which the tear may have extended under the pressure of the brain.

What, then, are the peculiarities of occipital encephalocele as illustrated by these two cases? They agree in the exaggerated development of the infundibulum, and the dropsical pouch on each side in front of the hemispheres; and in these points may be found sufficient explanation of their whole cephalic structure. The lateral pouches appear to be dropsical olfactory bulbs. The infundibulum is a prolongation of the thalamencephalon, from which the olfactory bulbs likewise take origin. There has been dropsy, therefore, of the thalamencephalon before the closure of the communication with the olfactory bulbs; and this dropsy is seen in Specimen IV. to have taken place after the walls of the second cerebral vesicle were sufficiently strong to resist its distending force, and to have pressed on the hemispheres so as to interfere with their growth, while in Specimen II., no doubt, it had entered the hemisphere vesicles and distended them. The hinder part had still been the portion of the roof of the skull least securely united in the middle line, and thus gave way before the pressure with which the brain was pushed back by the dropsical distensions in front, which were thus left in possession of the cranial cavity.

That dropsical enlargement of the olfactory bulbs and infundibulum should thus give rise to occipital encephalocele is exceedingly remarkable when taken in conjunction with what I demonstrated in a former memoir in this *Journal*,—that in cyclopia there is dropsical enlargement of the roof of the thalamencephalon, including the pineal body.¹ But in cyclopia there is not only a mesial eye, but also a single vesicle or mass to represent the hemisphere-vesicles; also the infundibulum, so far from being enlarged, is sometimes absent, and there is no

¹ "On the Brain of Cyclopians," *Jour. Anat. and Phys.*, xii. 518.

vestige of olfactory bulbs. Further, the dropsical vesicle found in cyclopia is also found in agnathia or perocephalus, but in that form there are the further peculiarities that the nose and eye have disappeared altogether, as has also the mass representing the hemisphere-vesicles, and that the first visceral arch, as well as the middle and lateral frontal processes of the embryo have been imperfectly developed, and that the clefts in connection with the external ears remaining open, and being approached one to the other, are undifferentiated from the buccal orifice. One other set of facts we must take into account, namely, that in cyclopia and perocephalus the vault of the skull is complete, and the hinder parts of the cerebrum normal, as are also the spinal cord and its coverings. To attempt to explain these things is to launch still further into the regions of hypothesis than I have been already obliged to do; still I think that the road to a rational explanation may be pointed out.

The unaltered condition of the corpora quadrigemina and parts behind it points to these parts being shut off sufficiently from the parts in front to preserve their form. As the infundibulum is not enlarged, while the region of the pineal body is certainly the main seat of the distension, the constriction must be between the two, a position which exactly corresponds with the optic tracts.¹ The cyclopic dropsy is probably of later origin than the anencephalic, and cannot on that account split up the parietes enclosing the brain behind. On that very account it does more injury in front, and induces a kyphosis or downward curvature, as well as a rotation inwards of the lateral parts for the growth of the face. Nor can these effects be counteracted as in anencephalus by bending backwards of the neck, seeing that the cervical part of the column is closed in and resistant. Thus in cyclopia the primary optic vesicles, which, according to this theory, must have been already formed, are crowded together, to be surrounded by a common globe, and the frontal processes pushed forwards as a proboscis in front of the mesial eye so formed; while in perocephalus the crowding of parts

¹ Personally I have little doubt that embryologists are mistaken in considering the infundibulum as belonging to the thalamencephalon. It probably is really mesencephalic in origin. For in the embryo chick of about thirty hours one can see that the optic commissure corresponds in position with the constriction between the first and second cerebral vesicles.

having been greater, the suppression of structures is carried to a greater extent.

The chick, Specimen XI., is of special interest because, unlike cyclopia in mammals, it combines a ruptured brain and cranium with a cycloplan eye, and the fusion of buccal orifice and external ears with the presence of a lower jaw.¹

In bringing these remarks on the cerebro-spinal axis to a close, I may note that there is still considerable difficulty in accounting for the total absence of the cord in open spina bifida. Four causes might be mentioned as possible agents, namely, exposure, pressure, exhaustion of the tissue elements, and stretching. Mere exposure I cannot entertain as a cause which could result in the smooth and entire membrane which we find in place of the cord, for the liquor amnii could scarcely be more detrimental to the growth of nervous tissue than the fluid in such a cervical spina bifida as Specimen II. Nor can pressure account for the phenomena, as the pressure, where there has been any, is removed at an early date. The destructive effects of stretching I have in a previous memoir shown in the case of appended monsters.² But stretching by the growth of neighbouring parts means comparative arrest of growth in the part itself, and thus we are thrown back on the fourth alternative, that such arrest really takes place in consequence of the proliferating power of the texture having been previously exhausted by overaction. Still the explanation seems scarcely sufficient, unless we suppose that the arrest in growth, and stretching of structure so arrested, prevent the development of blood-vessels.

STRUCTURES ENLARGED IN THE SPECIMENS DESCRIBED.

A most obvious instance of enlargement of structure is seen in the elongation of the cranial nerves in the cases of encephalocele. Here we have an example of nutrition keeping pace with stretching, beautifully seen in Specimen III., and contrast-

¹ As the hatching of an anencephalic chick has been considered as a rarity, I may note that I have been presented by Mr. John M. Campbell with a chick fully hatched which is double bodied, and with one neck and one anencephalic head.

² "On Double-Bodied Monsters, &c." *Jour. Anat. and Phys.*, viii. 255.

ing with the destruction of texture by the same cause in the upper part of the medulla oblongata of the same specimen. The same sort of elongation of nerve trunks occurs in the upper spinal nerves of Specimen VII., and is not uncommon. In this instance, also, the elongation arises from stretching of the nerves between their origin and their exit, and seems to indicate that in later development the superficial membrane in the lower part of its extent had refused to elongate farther, and had thus stretched the upper nerves.

The most extraordinary instance of enlarged structure is, however, the enormous laminated tubercle, three quarters of an inch long, of the cerebellum of Specimen I. Here is a structure in ordinary circumstances closely pressed on by other parts, which in this instance has obviously hung in a larger space caused by effusion of fluid. The fluid has pressed upwards on the cerebellum, and interfered with the normal development by means of which the edge of the posterior velum, originally directed downwards, comes to be turned forwards. But the laminated tubercle hanging free in this fluid has been very differently situated from what it usually is when its growth is resisted by solid structures. The mere absence of accustomed resistance has been shown by my friend and senior demonstrator, Dr. Allen, to be sufficient to lead to elongation of bone in the case of the head of the radius and the odontoid process;¹ and in this instance there has been removal of resistance of solids preventing elongation, and the pressure of fluid has been substituted, pressing equally on equal surfaces and in a direction at right angles to those surfaces.

Another instance of enlarged structure in the specimens described is found in the expansion of the vertebral laminæ in open spina bifida in the dorsal and lumbar regions. The phenomenon is not met with in the cervical region, because the vertebræ there are crushed by the bending which takes place. But the constancy of the shape of the large flat plates into which the dorsal and lumbar laminæ are developed is very remarkable. It is such a constancy as is comparable with the effects of heredity,

¹ "On Anatomical Changes induced by Dislocation Backwards of the Head of the Radius in Early Life," *Glasgow Med. Jour.*, July 1880; and "On Tertiary Occipital Condyle," *Jour. Anat. and Phys.*, xv. 65, Oct. 1880.

and recalls to mind other instances of a given interference altering in an explicit manner structures from their hereditary form. Of this sort are the effects of gall insects on different plants; also the growth of calcified corda dorsalis in renewed tails of lizards; phenomena which ought to stimulate the reflection of any one who may be disposed to explain every extraordinary structure which he meets with by deriving it from a purely hypothetical ancestry. Truly, we shall not find the full virtue of the law that environment modifies living forms, unless we appreciate, as has never been done, that it applies to every textural unit of the body, and that every vital action is the result of living particles and their surroundings acting and reacting one on the other. In this instance, the circumstance that the blastema from which the vertebral laminæ have been early derived has been thrown outwards must have modified the pressure to which they have been subjected, especially on the surfaces usually internal, but by eversion becoming superficial.

Another instance of enlarged development as a collateral consequence of a larger deficiency is seen in the enlargement of the mesial palatine processes of the intermaxillaries in connection with the cleft palate of Specimen II. They have beautifully expanded to form together a broad groove on which the vomer rests, exactly as one sees in the carnivora (fig. 3). This is the typical form of this part in mammals, but it is not found in normal circumstances in man, neither is it found in apes nor in monkeys. Yet, remaining potentially present, and as if suppressed for so long by mere mechanical causes, the peculiarities of this morphologically important part of the skeleton spring into view when these restraints are accidentally removed.

In this place I may also point attention to a phenomenon to some extent illustrating the converse of the principle with regard to pressure of which I have been furnishing examples. I allude to the collapsed cranial vault in anencephalus. When rupture has been complete, the blastema from which the roof bones, such as the parietals, is to be developed is quite displaced, and one does not wonder that when the ossification appears it should take the form of a thicker and unexpanded bone; but in cases such as Specimens III. and IV., where there has been no rupture in the frontal and parietal regions, one sees the effect of

the absence of the normal distending influence on the vault exercised by the growth of the brain. So also in Specimen II. the vault is small from want of growth of the brain, while in hydrocephalus the normal centres of ossification form more expanded plates than usual, and new centres of ossification arise around them to supplement them when they fail.

THE DISPLACEMENT OF VISCERA IN SPECIMEN IV.

Thoracic hernia of abdominal viscera is by no means unknown. Indeed, it occurred in Specimen II., but, owing to an accident, the parts were destroyed without being properly investigated. In an interesting account of a remarkable case of hernia diaphragmatica spuria sinistra, Wenzel Gruber¹ has given references to a number of cases of that sort previously described. But in the affection so named, the œsophagus passes into the abdomen, while the intestines enter the thorax by a deficiency in the left side of the diaphragm; while in the specimen which we have before us, although there is in like manner a large part of the alimentary canal lodged in the thorax, the cause and the details are totally different.

The commencement of the stomach in the neck at the level of the larynx is to be explained by recollecting that in very early fœtal life the stomach is seen lying longitudinally in the visceral cavity, with its œsophageal extremity immediately below the bifurcating pouch which is the first indication of the respiratory organs. The lungs, as they develop, descend into the visceral cavity, and the heart descends with them, while the stomach is, as it were, pushed before them, and the œsophagus at the same time brought into being by the descent of the stomach. In point of fact, the descent of the œsophageal end of the stomach, and the consequent turning of the stomach with its left side foremost, may be described as the fundamental cause of the lesser sac of the peritoneum.² What has taken place in this fœtus is, that at an early period, when the stimulation took place which produced the spina bifida, the spinal cord, the

¹ Virchow's *Archiv*, xlvii. 382.

² "The Peritoneum of the Human Subject illustrated by that of the Wombat," *Jour. Anat. and Phys.*, iv. 198, May 1870.

notochord and the commencement of the stomach became all firmly united, so that the stomach could not descend. But the thoracic viscera descending as usual, the diaphragm shut in the thorax below at the usual level, which happened to be just a little lower than the level to which the pylorus reached. Thus the narrow neck of the primary loop of intestine supplied by the superior mesenteric artery, the neck formed by the pylorus above, and the middle of the transverse colon below, came to be placed immediately above the diaphragm. Now, it is certain that the growth of this primary loop, as I pointed out many years ago, takes place in two stages,—the first a growth which, starting near the pylorus, forms the duodenum, and elongates the whole small intestine; the second, a growth from the colic end of the loop, which transfers the cæcum to its adult position. In this instance both ends of the loop were above the diaphragm, therefore both stages of growth went on within the thorax, and the condition of matters was brought about which was found. Also, the duodenum being developed within the thorax, and the cœliac axis coming off from the thoracic aorta, and the portal vein being fed from branches within the thorax, it naturally resulted that the portal fissure of the liver was pulled upon, and that the Spigelian lobe became visible within the thorax.

POST-ANAL DIMPLE.

In Specimens I. and VI. I have stated that there was a post-anal dimple. In both cases it was closely adherent to the tip of the coccyx. The depression was of a very distinct character, but expressed by the word dimple. Such a depression has, as Professor Turner kindly points out to me, been mentioned as an occasional occurrence by Luschka,¹ Hyrtl,² and Ecker,³ and, according to Mr. Lawson Tait,⁴ is by no means uncommon; but it is only recently that it has attracted my attention. I have

¹ *Anatomie des Menschlichen Beckens*, 1864, p. 57.

² *Topogr. Anat.*, 6th edition, p. 134.

³ *Archiv. für Anthropologie*, 1879, xii. p. 133. Professor Turner also tells me that about twenty years ago he saw a well-marked post-anal dimple in an adult male, and has a cast of the region in his possession. He subsequently saw another example in a living male child shown to him by Dr. Arthur Gamgee.

⁴ "On the Occurrence of a Sacral Dimple," *Report Brit. Assoc. Science*, 1878.

only seen one instance of a large and deep dimple in the adult. It was in a female subject, and the pelvis was preserved. It exhibits a sacrum of very remarkable appearance, there being but a slight longitudinal concavity on its anterior surface, while posteriorly the tip lies in a straight line with the extremities of the spines. It is $4\frac{1}{2}$ inches broad at the base, and $3\frac{3}{4}$ inches long, with a coccyx only half an inch long thoroughly united with it. In the anatomical collection in this University there is only one other example of straight sacrum. In it a rod laid along the front of the upper sacral vertebræ lies more than half an inch in front of the lower end, but there is a well-developed coccyx, and the length of the sacrum is $5\frac{1}{4}$ inches.

Altogether, I have no doubt that the shortness of the sacrum from the subject with the dimple was the result of arrest of growth in the notochord, and that a well-marked dimple in the position described always results from that cause.

THE VARIETIES OF LUMBAR AND SACRAL SPINA BIFIDA.

Since writing these pages, Dr. Morton of this city, whose successful treatment of spina bifida is justly a subject of interest to the profession, has attracted my attention to the question of the position of nerves in cases coming before the surgeon; and with him I have looked at the specimens in William Hunter's collection in the University of Glasgow.

Of preparations from ten different cases, only two have the tumour completely covered with true skin. One of these (49a) is a tumour $\frac{3}{4}$ inch in diameter. In it the cavity shows on the deep side a slight linear depression as if communicating with the cord which is situated in front; and on one side the deep wall is dissected away, showing the sacral nerves lying normally and coming from a level above the linear depression. The other skin-covered specimen (47) is large. It was unopened; but with the kind permission of Professor Young, the curator of the Hunterian Museum, I have opened into it, and find, as I expected, the cord in this instance also on the deep side of the dropsical cavity. This I expected, because I judged that such a tumour must be the result of delayed closure of the cord, or reopening of its canal behind at an early date. In the bottom

of the cavity there is a depression, in connection with which the cord seems to end; at the same time there is a communication with the arachnoid space.

Without entering into detailed description of the other specimens, it may be stated that they all of them present membrane of a non-cutaneous kind on part of their surface. In some of them the cord seems to end distinctly in connection with the superficial membrane. Some show the nerves of opposite sides coming off from the membranous surface crowded together in the middle line, there being evidently dropsy of the anterior sac of the arachnoid to such an extent as to lead to obliteration of the posterior sac. In others the nerves arise from the covering of the tumour in two series, which may be marked on the surface by punctiform depressions at their attachments, or which may spring from the lines of junction between a central membranous part of the tumour and two lateral skin-covered parts.

For practical purposes, spina bifida may be described as divisible into two kinds, the skin-covered and the membranous. The skin-covered are posterior to the spinal nerves; the membranous are traversed by nerves which arise from the membrane. But it ought to be understood that these nerves proceed to the intervertebral foramina, and have no connection with developed spinal cord.

EXPLANATION OF PLATES XI. AND XII.

Fig. 1. Basal view of brain of Specimen III., about two-thirds of natural size. *a, a*, The portions of the hemispheres which were contained within the cranium, each exhibiting a dropsical hollow, the whole mass beneath the constriction lay outside the skull; *b, b*, elongated cranial nerves; *c*, medulla oblongata; *d*, enormously enlarged infundibulum with vestiges of optic commissure and nerves in front of it; *e, e*, dura mater partially removed from the hemispheres; *f, f*, vestiges of hemispheres of cerebellum.

Fig. 2. Cervical, dorsal, and four lumbar vertebræ of Specimen II.

Fig. 3. Skeleton of cleft palate, showing the arrangement of the vomer and intermaxillary bones of Specimen III.

Fig. 4. View of the displacement of viscera in Specimen IV. *a*, ear; *b*, symphysis of lower jaw; *c*, thyroid gland covering the larynx; *d, d*, lungs; *e*, heart; *f*, placed on the bodies of cervical vertebræ

above the brachial plexus and the gap which separates the right from the left moieties of vertebral bodies and gives passage to the tissue which binds the stomach to the dura mater; *g*, stomach; *h*, spleen; *i*, vermiform appendage of cæcum; *k*, diaphragm; *l*, liver; *m*, umbilical cord; *n*, cord left by obliterated omphalo-mesenteric vessel (cord of Allen); *o*, rectum; *p*, urinary bladder; *q*, lobulus Spigelii; *r*, upper end of the obliterated omphalo-mesenteric vessel.

Fig. 5. Dorsal and four upper lumbar vertebræ of Specimen I.

Fig. 6. Portion of brain and spinal cord of Specimen I. *a*, corpora quadrigemina; *b*, *b*, hemispheres of cerebellum, with vallicula and vermiform process almost completely separating them; *c*, the extremity of the enormously elongated nodule; *d*, the recess in which the point of the nodule lay, and above it the opening of the central canal into the elongated 4th ventricle; *e*, the section of the spinal cord, showing a dilatation of the central canal which has been ripped open and found to end blindly without reaching up to the 4th ventricle.

Fig. 7. Cerebellum, medulla oblongata, and spinal cord of Specimen II., seen from behind. *a*, The lower end of the part of the cord flattened out in continuation of the 4th ventricle.

Fig. 8. Membranous area of spina bifida, and the tumour containing the brain, of Specimen IV. The tumour has been cut into by means of a transverse section; and the upper part, *a*, of its wall has been thrown forward from its natural position continuous with the cut edge *b*; below *a* is seen the falx cerebri; beside *b* is a foramen opening into the interior; *c*, *c*, right hemisphere partially cut across by the transverse section; *d*, left hemisphere a good deal injured; *e*, *e*, basal ganglia; *f*, membranous area over spina bifida; *g*, delicate membrane stretched across, limiting a dropsy of the 4th ventricle.

Fig. 9. Integuments, roots of nerves, and membranes removed from over the skull and spinal column of Specimen VI., and seen from the deep aspect. *a*, Basal view of the small hollow tumour representing the brain; and below *a*, the basilar artery bifurcating; *b*, a tough fibrous thickening of the dura mater where it projects forwards into the depression between the skull and the vertebral column; *c*, *c*, two strips of dura mater, from which emerge the right and left spinal nerves; *d*, anterior sac of the arachnoid, or that part which lies between the origins of nerves of the right and left sides; *e*, *e*, the right and left moieties of the posterior sac of the arachnoid; *f*, *f*, fifth cranial nerves.

Fig. 10. Magnified view of Specimen X., an embryo chick which has deviated from normal development about the end of the first day by exaggerated growth of the epiblast, which has become folded and frilled.

Fig. 11. Magnified view of a chick $\frac{3}{4}$ -inch long, seen from the left. The upper aspect of the bare encephalon is seen, and at its back part the calamus scriptorius continuous with the central canal.

Fig. 12. View of the head of the same from the right, showing the common orifice of the mouth and ears, and the small cyclopian eye.